DOE/NV/11718--466

ImageTool

Stuart A. Baker*, S. D. Gardner, M. L. Rogers, F. Sanders, T. W. Tunnell

Bechtel Nevada, Los Alamos Operations, MS C320, Los Alamos, NM 87544

ABSTRACT

ImageTool is a software package developed at Bechtel Nevada, Los Alamos Operations. This team has developed a set of analysis tools, in the form of image processing software used to evaluate camera calibration data. Performance measures are used to identify capabilities and limitations of a camera system, while establishing a means for comparing systems. The camera evaluations are designed to provide system performance, camera comparison and system modeling information. This program is used to evaluate digital camera images. ImageTool provides basic image restoration and analysis features along with a special set of camera evaluation tools which are used to standardize camera system characterizations. This process is started with the acquisition of a well-defined set of calibration images. Image processing algorithms provide a consistent means of evaluating the camera calibration data. Performance measures in the areas of sensitivity, noise, and resolution are used as a basis for comparing camera systems and evaluating experimental system performance. Camera systems begin with a charge-coupled device (CCD) camera and optical relay system and may incorporate image intensifiers, electro-static image tubes, or electron bombarded charge-coupled devices (EBCCDs). Electro-optical components provide fast shuttering and/or optical gain to camera systems. Camera types evaluated include gated intensified cameras and multi-frame cameras used in applications ranging from X-ray radiography to visible and infrared imaging. It is valuable to evaluate the performance of a camera system in order to determine if a particular system meets experimental requirements. In this paper we highlight the processing features of ImageTool.

Keywords: image intensifier, CCD, radiography, electro-optic, imaging, camera performance, image evaluation.

1. INTRODUCTION

Bechtel Nevada is responsible for providing electronic imaging support to the U. S. Department of Energy for a wide range of experiments. Our support covers the entire life of a camera system, from design and fabrication to data acquisition and image analysis. Many of the camera systems are fast-shuttered intensified cameras, both commercial and custom-built. Due to the wide scope of imaging applications, similar types of camera systems are used on a variety of projects. To aid experimenters in evaluating and comparing their camera systems, we have developed a standard set of camera tests that provide essential system performance information without data overload. Camera types include gated intensified cameras and multi-frame cameras used in applications ranging from X-ray radiography to visible and infrared imaging. These camera systems may incorporate a variety of electro-optical components including micro-channel plate (MCP), proximity focused diode (PFD) image intensifiers, or electro-static image tubes. Key performance parameters include sensitivity, noise, dynamic range, and resolution. We have developed a camera calibration sequence that is used to standardize our data acquisition methods and image analysis process. This approach requires minimal data acquisition time and allows the use of automated data processing routines. This streamlined process provides quick feedback on a camera system's capabilities and limitations while establishing a means for making standardized camera system evaluations. The image analysis involves the development of a set of image processing algorithms for analyzing calibration images. The algorithms have been compiled into a software package called ImageTool. This program is used to evaluate digital images recorded with CCD cameras. The software runs as an Interactive Data Language (IDL) software 'Widget.' Overall system performance in an experiment is dependent on environmental

* Correspondence: Email: bakersa@nv.doe.gov; Telephone: 505-663-2039; Fax: 505-663-2003

conditions such as optical source characteristics, optical relay or imaging system, background conditions, and camera characteristics. The image processing tools developed provide an experimenter with the ability to quickly evaluate and document the performance of their imaging system in a particular experimental setup with a minimal set of calibration images. This paper highlights the special features of ImageTool in the areas of image file manipulation, image restoration, and performance evaluation measures.

2. IMAGETOOL FEATURES

ImageTool is designed to ease the burden of repetitive file manipulation tasks as well as provide sophisticated image analysis capabilities. By allowing multi-file processing and image pre-processing, the manual labor involved in analyzing large amounts of data is greatly reduced. Some image restoration capabilities are included to allow the image information to be maximized. The specialized image evaluation tools are a key segment of ImageTool which generate the system performance results.

2.1. Image File Manipulation

Multi-file processing along with image pre-processing, allow your energy to be focused on evaluating the results of your processing and not just getting through the repetitive tasks. Multiple image files may be selected to be loaded in a single process. This is especially time saving when background subtraction and/or flat field correction is applied to the same data set. Figure 1 shows multiple files selected for loading with background subtraction.

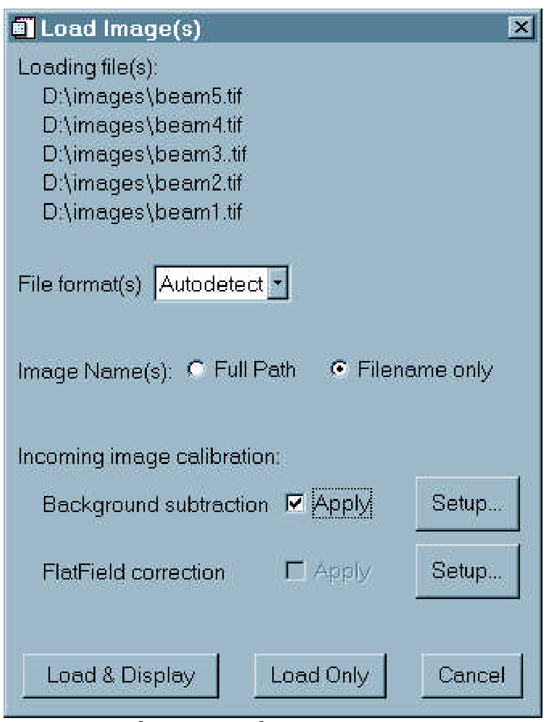

Figure 1. Load image panel.

2.2. Image Restoration

Image restoration involves the ability to restore image clarity and detail without distorting image information. Key components in providing image clarity are the ability to remove fixed pattern noise, removal of bad pixels, and image de-warping. Sources of fixed pattern noise include the CCD, an image tube, or scene illumination. Fixed pattern noise is generally removed with flat field corrections. Bad pixels can be eliminated with a smoothing feature called Star Removal. Stars, which are so-called because their appearance is similar to bright stars in a night sky, are identified as "hot" pixels in the CCD image. A "hot" pixel is a pixel with a value much higher than the range of the scene recorded. Stars may inhibit image recognition due to image display contrast. Image de-warping can remove pincushion or barrel distortion introduced by an optical relay system or an electro-static image tube. The image buffer panel shown in Figure 2, indicates the types of process applied to selected images in the name<status> heading, which may be saved with the image file.

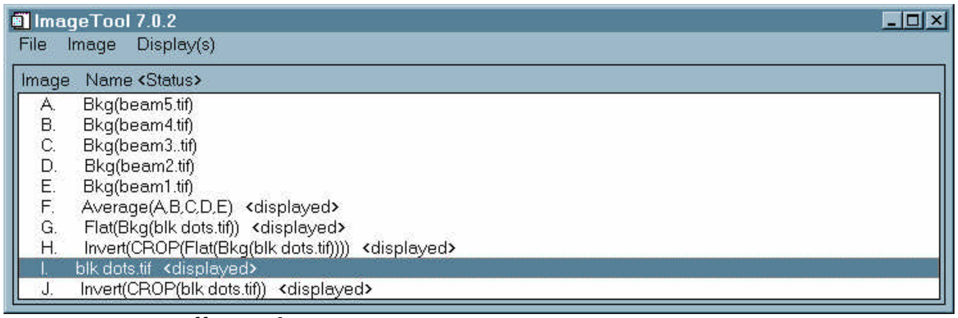

Figure 2. Image Buffer panel

2.3. Image Evaluation

The image evaluation component of the program provides three special functions, in a separate menu: modulation transfer function (MTF); detective quantum efficiency (DQE); and noise-power spectrum (NPS). The modulation function is used to expedite resolution target line pair computations. Line pair targets are generally the quickest way to get a measure of a system's resolution capabilities. The MTF function has been added to enhance resolution measurements. This function allows MTF curves to be quickly calculated from an edge target image. MTF curves are more powerful then a simple line pair modulation, since one plot tells you something about the resolving power over the entire detectable spatial frequency range of the camera as well as providing a system modeling component. The DQE function allows computation of the systems fidelity in sensitivity and signal to noise characteristics. The NPS function measures system noise as well as being useful as a modeling parameter. These functions are described below in greater detail.

3. IMAGE PROCESSING

Many of the once manual image processing functions have been automated, and they are performed transparently to the user. For example, automated image pre-processing and multi-file processing save the user much time. Image enhancements may be used to improve resolvable image detail. These features may be used to prepare an image for analysis or presentation.

3.1. File Formats

ImageTool can read most any image file format, a few standard ones automatically. Unrecognizable formats will require image parameters to be input by the user. The required parameters include data type, header length, image pixel array dimensions, and byte order. Multiple files may be selected for loading in a single operation. The Load Image panel (Figure 1)retains the latest setting used during your processing session to allow easy loading of subsequent image files.

3.2. Image File Pre-Processing

This feature allows the user to bypass several manual steps required in other image analysis packages. The pre-processing options are shown in the Load Image panel (Figure 1). The time saving steps include loading individual data, background and flat field images, changing the data type of each, performing background subtractions on data and flat field, then performing flat field data division. The data type must be changed to floating point to allow negative and fractional values of integer data images. These steps are performed automatically during image pre-processing while an image file loads; the user only needs to select the appropriate correction files. The effects of image pre-processing are illustrated in Figures 2 and 3. Once correction files are established, they are easily applied to future data images.

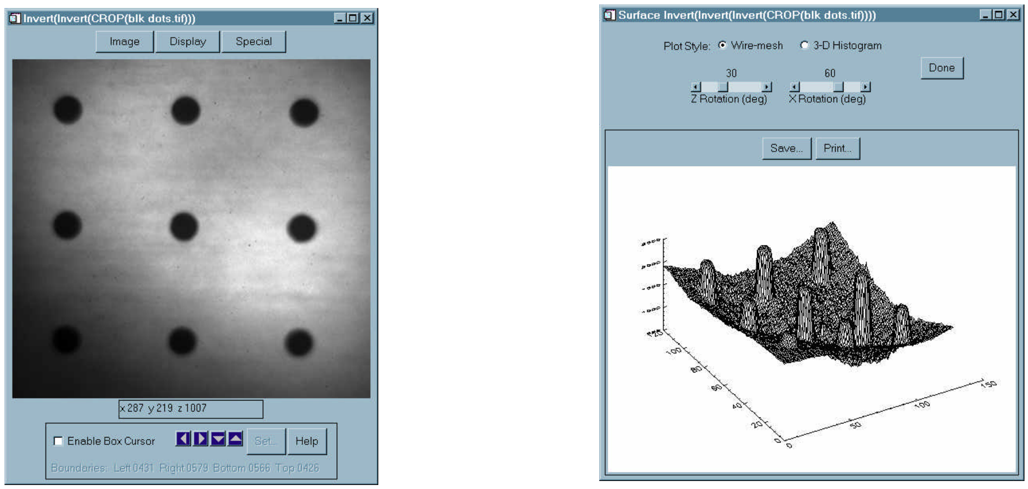

Figure 3. Original image with 3-D perspective view.

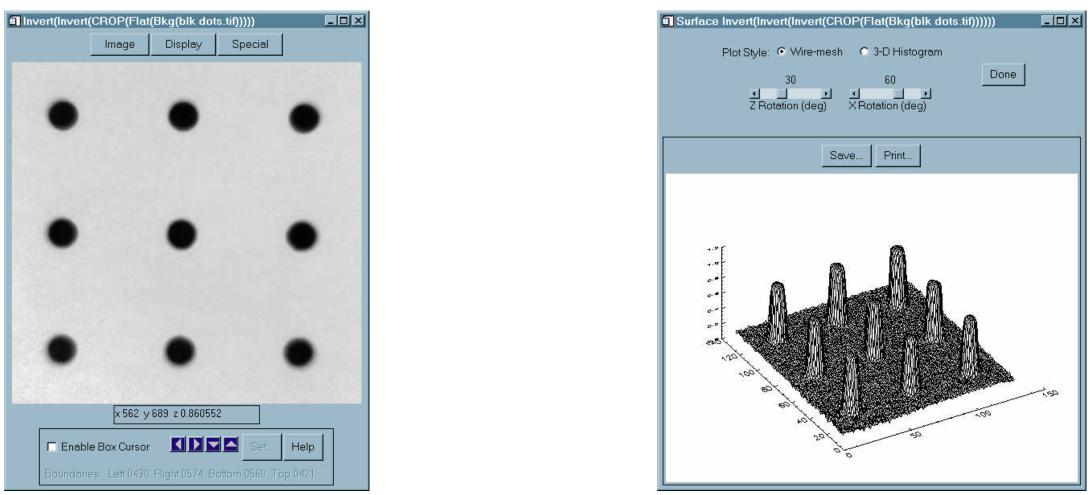

Figure 4. Pre-processed image with 3-D perspective view.

3.2.1. Background Subtraction

The Background Subtraction panel, shown in Figure 5, appears when this option is selected. It will subtract a saved background or bias image from a data image as the date image is loaded into the image buffer. The panel allows you to select a file from disk or choose an image in the image buffer shown in Figure 2. Once the background image is selected, you are allowed to convert the image to floating point to avoid arithmetic errors and allow data roll over to negative values. This maintains the appropriate signal level above background.

3.2.2. Flat Field Correction

The Flat Field panel in Figure 6 is used to divide a flat field image into a data image as the data image is loaded into the image buffer. Flat field correction is used to remove fixed pattern noise and intensity roll off in an imaging system. The manual processing steps are fully automated and are a great time saving feature, as image files are read into memory already to be analyzed. Flat field corrections are performed as a floating-point operation to allow fractional pixel values.

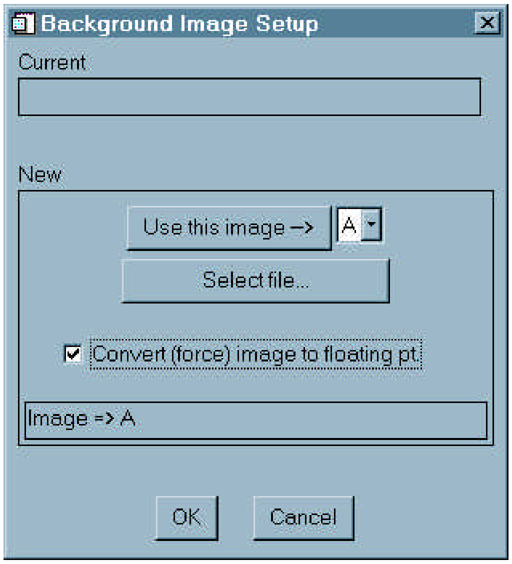

Figure 5. Background image panel.

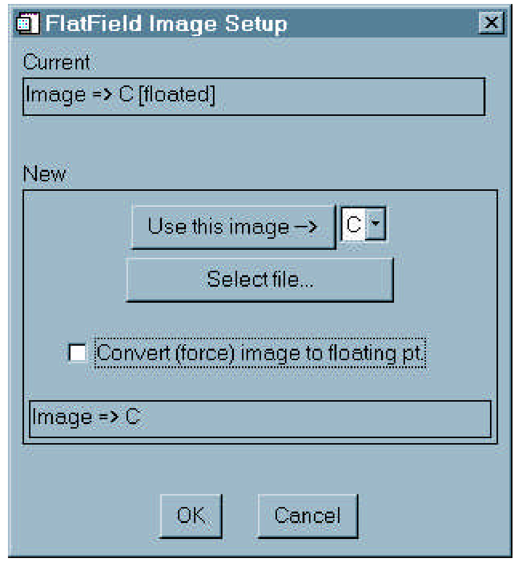

Figure 6. Flat field selection panel.

3.3. Multi-File Processing

Multi-file processing is another outstanding feature of ImageTool. In Load Image, you may select several images to be loaded in a standard Window File Open panel. Pre-processing features may be applied to all images as loaded. With multiple files loaded into the image buffer, image arithmetic or image averaging may be applied to multiple images. The Average Images panel is shown in Figure 7. The manual house keeping steps are taken care of for you. Multi-file processing is especially useful in evaluating multiple files of similar data, as in transfer curve data used to measure a system's dynamic range, to identify noise equivalent input (NEI),[1] and saturation levels.

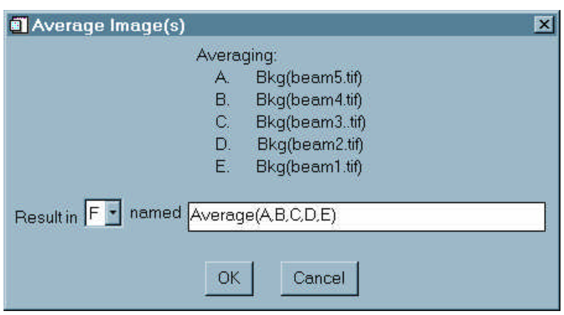

Figure 7. Average images panel.

3.4. Image Enhancements

There are several available image enhancement features for improving image recognition that were discussed in the Image Pre-Processing section. Many of the options are accessible from the Image Edit menu shown in Figure 8. The Image Buffer panel shown in Figure 2, lists the images loaded into memory, along with the processes applied in the image title. This image title heading may be saved with the image file as documentation of process applied. A couple of key image enhancements include a "star removal" filter and distortion correction. The "star removal" filter is especially useful for radiographic imaging applications, where X-ray sources may have increased unwanted bright pixels in recorded images.

Distortion correction is essential in restoring true image dimensions in systems where pincushion or barrel distortion is introduced by image tubes or optical elements. Distortion correction is currently functioning as a separate routine and is not installed in ImageTool at this time.

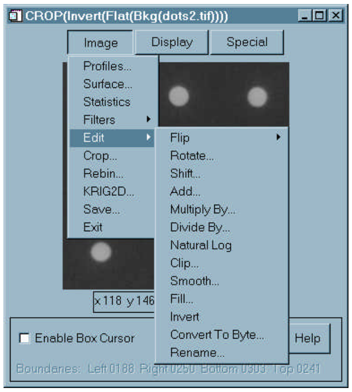

Figure 8. Image Edit panel.

4. IMAGE ANALYSIS

4.1. Resolution

System resolution is a key measure of system performance. A number of tools are available to improve analysis of system resolution or experimental data. The Profile routine will provide a live row or column profile of the single line of the cursor location in an image or region of interest. The Collapse routine will average or sum the pixel row or column values over a specified region of interest and plot the resulting profile. Line pair modulation calculations and MTF curves are described below.

4.1.1 Line Pair Modulation

The Modulation panel (Figure 9) is used to calculate the percent modulation detectable in the profile of a line pair resolution target. This is a contrast transfer function (CTF)[2] calculation for square bar pattern targets and MTF for square wave input. This process is described in detail in "*Evaluating intensified camera systems.*"[3] The Modulation panel allows the user to position a line cursor at the desired level of peak and minimum modulation and a baseline level. The percent modulation is then computed. This feature allows quick evaluation of system focusing tests.

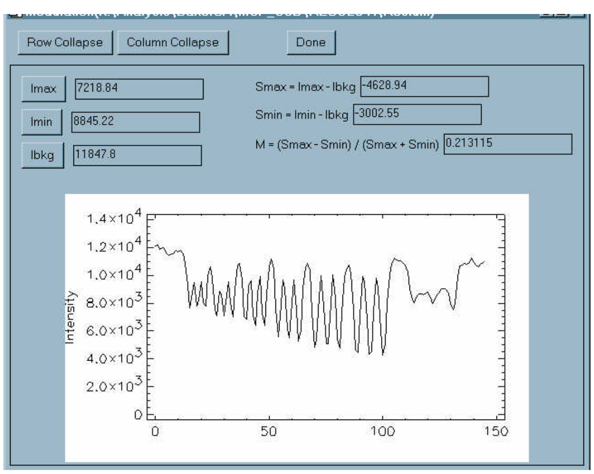

Figure 9. Modulation panel.

4.1.2. MTF process

MTF processing involves loading and pre-processing an edge image, then defining the region of interest (ROI) from which to extract an edge profile or edge spread function (ESF). The ESF is used to compute a line spread function (LSF) and an MTF[4]. Both LSF and MTF are saved to a file. The MTF is plotted with an active cursor to identify particular locations on the plot (Figure 3). The 50 percent modulation point is identified as the cut-off frequency (f_c), and it is used for performance comparisons. This MTF routine has a special feature to remove critical rotational alignment dependence for the ROI to the edge. The MTF process is described in detail in "*Evaluating intensified camera systems.*"[2]

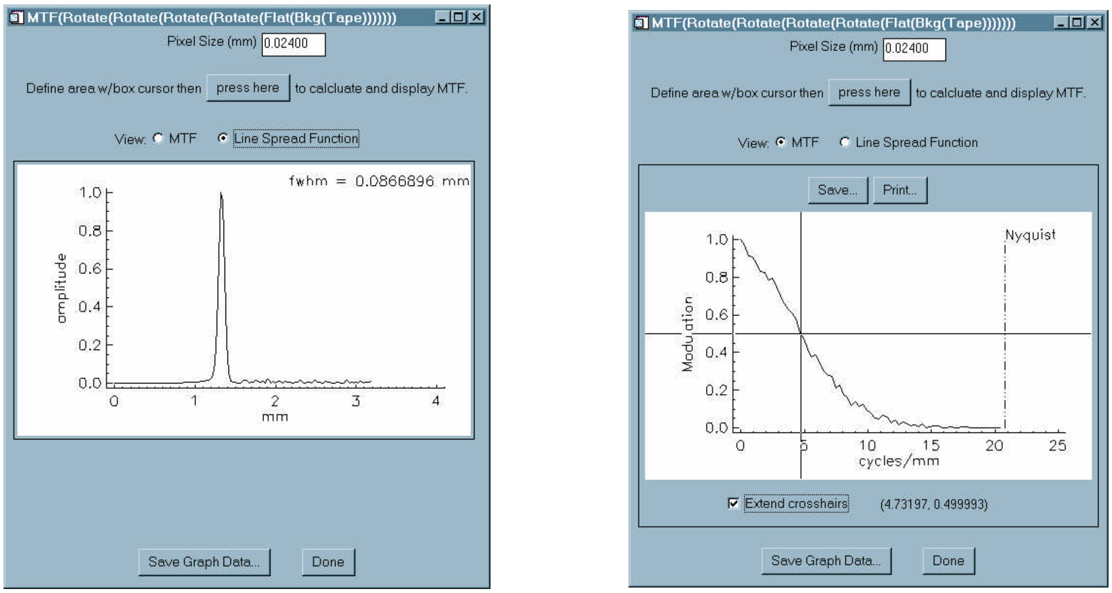

Figure 10. MTF panel with line spread function.

4.2. Detective quantum efficiency (DQE)

Detective quantum efficiency (DQE) is a measure of a system's signal recording fidelity. High DQE detectors are preferred for low light level imaging. DQE is measured in terms of signal to noise ratios (S/N). The signal level output is dependent on the quantum efficiency, QE, of the detector and gain of the system. The noise output is dependent on the amount of noise introduced by the environmental background conditions, gain stages or readout camera electronics. According to Dainty and Shaw's "*Image Science,*"[5] DQE is calculated as:

$$DQE = (S/N)^2_{\text{OUTPUT}} \,/\, (S/N)^2_{\text{INPUT}}\,, \tag{1}$$

The signal to noise output is a straightforward statistical measurement of the mean signal level and standard deviation (noise) of the mean signal area. The signal and noise levels are measured above background after fixed pattern noise has been removed from the data image. The signal and noise are measured for a measured input energy density, w_e.

Per Dainty and Shaw's "*Image Science,*"[5] the input signal is the number of photon quanta input, q, and the noise input is the square root, $\sqrt{q}$. In "*Performance of image intensifiers in radiographic systems*"[6] the photon density, q_p, is calculated as a function of total energy input, Q_e. In practice, a simpler method is to calculate q_p as a function of energy density input, w_e, (J/cm^2). This simple measurement integrates energy density volume over time to give the energy density as a function of area. To start, the input photon density is calculated from the energy density measurement. The photon density, q_p, is calculated from an input energy density measurement as shown in "*Evaluating intensified camera systems.*"[3,7,8] The quanta input is then associated with the resolving power of the imaging system. A point spread function measurement is used to calculate the area of a resolution element, A_{res}.

The quanta input is then:

$$q = q_p A_{res} \tag{2}$$

$$(S/N)_{INPUT} = q / \sqrt{q} = \sqrt{q} \tag{3}$$

4.3. NPS processing

NPS processing may be run on raw data files or on processed data (Figure 7). Flat field corrections with fixed pattern noise removal will improve the results of this analysis. Noisy imaging systems will have more area under the NPS curve than less noisy systems. The NPS process is similar to the MTF process, but applied to flat field illumination images instead of an edge target image. This parameter may also be used in system modeling. The NPS is calculated using straightforward Fourier methods as described by Stierstorfer and Spahn.[9]

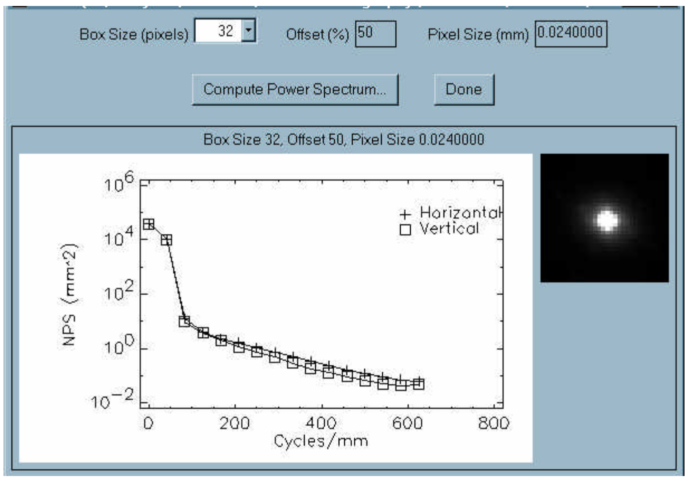

Figure 11. NPS panel.

CONCLUSION

ImageTool is a stand-alone package capable of processing and documenting a camera system's calibration and experimental data with straightforward, consistent techniques. The software tool is an excellent means of evaluating a large amount of information in a short amount of time. ImageTool provides valuable camera comparison and performance information as well as system modeling information used in predicting experimental results. Evaluation techniques are being streamlined to provide essential performance information on a camera system in a simplified manner. Our effort to improve camera evaluation techniques and capabilities continues to evolve as new evaluation techniques are developed and process modifications are implemented. Software development is being used to blend traditional spatial domain analysis with frequency domain analysis to interlace the understanding of evaluation parameters. ImageTool is designed to be a multi-user program available to different teams of people working with similar types of camera systems. By acquiring the appropriate calibration data set, one can generate comparable calibration data through the consistency of data processing techniques. As camera systems are evaluated, their performance information is stored in a data base for performance records and comparisons. The MTF and NPS curves generated by ImageTool may also be used for system modeling. Future versions of ImageTool will incorporate improved automated processing functions with user-selected optional parameters as well as upgrades to data presentation.

ACKNOWLEDGEMENTS

This work was supported by the U.S. Department of Energy, Nevada Operations Office, under Contract No. DE-AC08-96NV11718.

This work has been done in collaboration with a number of individuals including but not limited to: Greg Cunningham,[b] Nick King,[b] Wil Lewis,[a] Steve Lutz,[a] Dane Morgan,[a] Karl Mueller,[b] Tom Tunnell[a], Mike Ulibarri,[b] Scott Watson,[b] and Mark Wilke.[b]

[a] Bechtel Nevada, [b] Los Alamos National Laboratory

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